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Guidelines for improved management of riparian zones invaded by alien plants in South Africa

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Abstract

This paper reviews the results of recent research on riparian vegetation recovery following the clearance of invasive alien plants. In Fynbos, Grassland and Savanna Biomes, riparian ecosystems were found to have relatively-high ecological resilience to invasion by alien plants, except in some situations of closed alien stands (75–100% aerial cover). Where alien invasion is the primary disturbance at a site, and invasion intensity is low (<75% cover, with some indigenous species present), the recovery of riparian vegetation structure and functioning is a realistic goal through alien clearance alone. Careful clearance of the aliens to avoid damage to indigenous species, while ensuring a high kill rate for resprouting alien species, is sufficient action to ensure ecosystem recovery. However, it is important that alien follow-up control is maintained at a sufficient frequency and that adaptive management is exercised to deal with unplanned events, such as fire or a high rainfall year, that may stimulate renewed alien recruitment. In closed alien stands, clearance may be sufficient to restore ecosystem structure and functioning in some situations, but not in others. To be realistic, restoration goals must take into account the planned future use of the riparian zone and the current ecological condition of the surrounding catchment area. Where ecological integrity of the catchment is low (highly transformed, fragmented), restoration of natural riparian vegetation structure or composition is untenable in most cases. A more realistic goal will be to restore basic ecosystem functions through providing a vegetation cover, comprising non-invasive (preferably indigenous) species, that is resilient to flood events and re-invasion by alien plants. The functions restored should include the buffering of the aquatic ecosystem through erosion control, and a return to more natural hydrological flows. In less-transformed catchments, restoring riparian ecosystem structure and composition is a realistic goal where closed alien stands are cleared by the “Fell & Remove” treatment. Seed banks provide indigenous herb and shrub species, but where recruitment is poor, especially after fire, active restoration is beneficial in facilitating vegetation recovery and suppressing alien recruitment. However, the costs and benefits of active restoration need to be further investigated. Simple decision trees with accompanying information boxes and species lists are presented to assist managers. Because of the complexity of the decision process, it is recommended that specialists assist project managers in drawing up site-specific restoration plans that dovetail with alien-clearing plans. This synthesis of research findings, on riparian restoration in alien-invaded riparian zones, provides guidelines for improved management, drawing mainly on papers in this Special Issue.

Keywords: Alien vegetation control; Fire; Fynbos; Grassland, Biological Invasions; Restoration; Riparian ecosystems; Savanna; Seed banks

1. Introduction

Worldwide, riparian zones have been degraded on a large scale. In many areas, catchment-scale hydrological modifications and invasive alien plants are among the most influential agents of degradation (Jansson et al., 2000; Holmes et al., 2005; Richardson et al., 2007). Many restoration projects are underway to correct changes to ecosystem structure and functioning caused by alien plant invasions. In South Africa, the primary motivation is to restore hydrological flows in rivers and deliver water benefits to humans, as the major invaders of riparian zones are trees which use more water than indigenous riparian plants and thus reduce water yields from catchments (Prinsloo

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and Scott, 1999; Le Maitre et al., 2002; Dye and Jarmain, 2004). Fig. 1 illustrates different riparian invasion scenarios in South Africa.

A review of the impacts of alien invasion and restoration potential in South African riparian ecosystems, identified both abiotic and biotic constraints to restoration at scales of local reaches to catchments (Holmes et al., 2005). It was concluded that in highly-transformed catchments, interventions at the reach scale (i.e. along short river lengths) may fail if important constraints at the catchment scale are not addressed (see Richardson et al., 2007). Such constraints include altered flow regimes and land-uses in the catchment, which lead to excessive

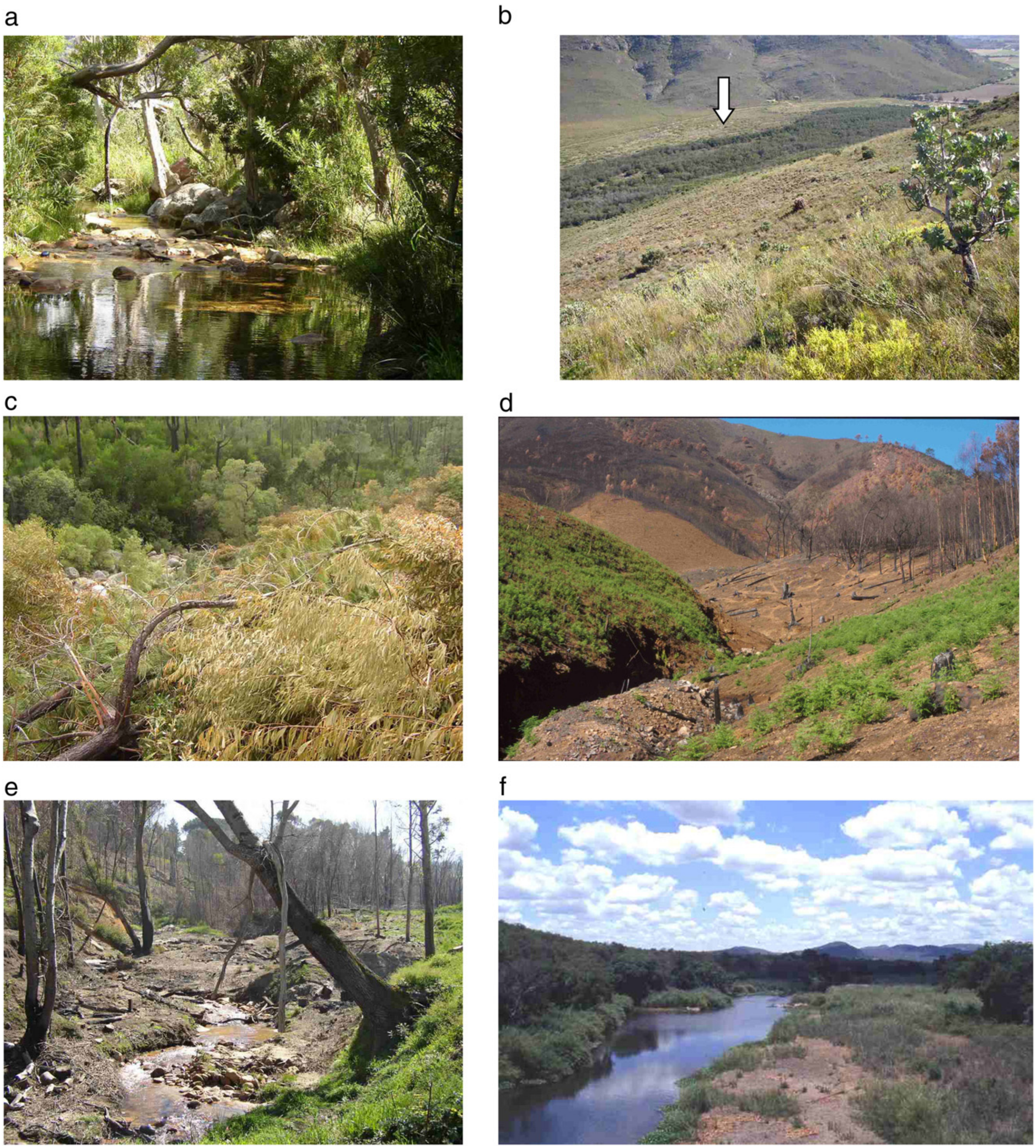

Fig. 1. Fynbos Biome (Western Cape; photo credits P. M. Holmes): (a) native riparian scrub with some forest elements; (b) aerial view of closed-canopy invasion by *Acacia mearnsii* in a foothill riparian area — indicated by white arrow; (c) “Fell Only” clearing treatment of a closed-canopy stand of mixed aliens (near side of stream); (d) riparian zone following a “Fell & Burn” treatment; (e) degraded stream supporting mainly *Eucalyptus* species invasion, after fire; Savanna Biome (Mpumalanga): riparian zone encompassing native riparian herbaceous and woodland vegetation (E.T.F. Witkowski); (g) invasion by *Xanthium strumarium* (T. Morris); Grassland Biome (Mpumalanga); (h) stand of mature *Eucalyptus grandis* adjacent to riparian zone (M. Beater).

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Fig. 1 (*continued*).

soil erosion. The ability to manipulate these abiotic factors will depend upon cooperation from surrounding land-users in relation to water-use and cultivation methods, as well as negotiations relating to water release from impoundments to meet the ecological reserve (i.e. environmental flow) (King and Brown, 2006; Blignaut et al., 2007). In relatively-untransformed catchments, there remain potential biotic constraints to restoration, including a lack of indigenous propagules in densely-alien-invaded catchments and a lack of suitable microsites for establishment following reach-scale alterations caused by alien plants (Galatowitsch and Richardson, 2005). The presence and extent of these biotic constraints remain to be tested in the different biomes of South Africa.

The largest initiative for alien plant clearing in South Africa, the national Working for Water Programme (WfW), has been in operation since 1995 (Van Wilgen et al., 1998), yet a recent analysis indicates that only 7% of closed-stand riparian invasions has been cleared to date (Marais and Wannenburgh, 2008-this issue). Most riparian zones are invaded to a greater or lesser extent: if all invasion densities are compressed to closed stands, this would be equivalent to 33% closed-stand invasion across the total perennial and non-perennial riparian area (Cullis et al., 2007). Thus, a huge task lies ahead if alien plant invasions in riparian zones are to be brought under control. It is now appropriate to take stock of the impacts of alien clearance efforts to date and to test the null hypothesis that alien removal alone (Box 1) will restore structure and functioning to riparian ecosystems.

The ecological rationale for WfW is that invasive alien vegetation reduces water yield, threatens biodiversity, and reduces the productivity of land (Anon, 2007). Implicit in the goal of enhancing ecological integrity, is the assumption that removal of alien vegetation alone will result in improvements to ecosystem structure and functioning. At regional and catchment scales this undoubtedly will be the case, as WfW strategic planning prioritises invasion fronts and outliers, thus preventing further invasion and degradation of ecosystems, and facilitating rapid recovery at recently-invaded sites (Anon, 2007). However at local scales, in situations where dense to closed alien stands have existed for some time, thresholds may have been passed whereby ecosystems no longer have the capacity to recover unaided after removal of the aliens, but require either vegetation manipulation, modification of the physical environment, or both (Whisenant, 1999). Several internal WfW best-practice documents (e.g. “Recommended Clearing Norms and Treatment Methods” and “The Revised Policy on the Use of Herbicides for the Control of Alien Vegetation”) specify appropriate clearing methods and herbicide use to maximise efficiency and facilitate decision-making for alien control. However, it is important to note that these tools are focussed on alien control rather than restoration and there may be instances where a deviation from the recommended approach is necessary to promote indigenous vegetation recovery.

In this Special Issue, research completed towards a project commissioned by WfW on ecosystem repair targets for alien-invaded riparian zones is presented, together with additional research papers that contribute to this theme (Table 1). The term “ecosystem repair” refers to actions that overcome limitations in both the abiotic and biotic components of the ecosystem, thus improving either functional integrity or biodiversity (Richardson and Van Wilgen, 2004). We attempt to derive clear and achievable goals for riparian ecosystem repair following alien plant invasion in three different biomes. Although restoration to some pre-invasion fully-functioning state may be an appropriate goal at sites that are lightly invaded or have only recently become densely-invaded, at long-invaded sites such a target may be unattainable in the short to medium term without very expensive interventions (Holmes and Cowling, 1997). We thus

Box 1

Potential methods for the removal of invasive alien trees from riparian zones (see Fig. 1.)

- Fell Only – Cut trees close to ground (apply herbicide to stump if a resprouter); leave slash on ground
- Fell & Remove – As above, but large wood (>50 mm diameter) is removed from the riparian zone
- Fell & Burn – As for Fell Only, then slash is burnt after drying out for several months
- Kill standing – Large trees are killed by ring-barking or frilling (applying herbicide into cambium layer)

Table 1
Scope of research addressed in the Special Issue

Issue	Variables
Geographical region/biome	Fynbos (east and west), Grassland, Savanna (Mpumalanga)
River order	Mountain stream, foothill, lowland/ flood-plain (latter in Savanna only)
Invasion intensity	Closed alien stands (Fynbos), lower density stands (light–dense) Grassland and Savanna
Invasive alien plant species	Woody transformers: trees and shrubs
Abiotic impacts	Flood event (Grassland, Savanna) Fire (Fynbos)
Research focus	Pattern: vegetation and seed bank structure, composition and diversity Process: patch dynamics
Ecosystem Repair	Unassisted natural recovery; assisted propagule re-introduction (latter in Fynbos only)

differentiate between “restoration”, defined as a reconstruction of a prior ecosystem including the re-establishment of former functions and characteristic structure, communities and species; and “rehabilitation”, defined as the re-introduction of important ecosystem functions, such as improving water infiltration or erosion control, to benefit ecosystem functioning at the landscape scale, but not necessarily biodiversity (Van Diggelen et al., 2001).

We base our target setting on the future desired characteristics of the ecosystem rather than being restricted to some historical ecosystem for which we may not have adequate understanding, or which might not be possible owing to irreversible ecosystem change (Hobbs and Harris, 2001; Hughes et al., 2005). Such a framework allows appropriate targets to be set, based on the degree of ecosystem degradation that has occurred and in relation to other environmental variables as well as the proposed future land-use in an area. The key questions for this research, within a time frame of the first decade of WfW, are:

a) What has been achieved in terms of ecosystem repair following removal of stands of alien trees and shrubs?
b) Have abiotic or biotic thresholds been passed that prevent natural ecosystem repair?
c) What is achievable in terms of ecosystem repair in each of the different situations studied and how could operations be improved?
d) What are realistic ecosystem repair goals for the different situations?

Finally, in this synthesis, we suggest monitoring criteria for rehabilitation and restoration in alien-invaded riparian zones and discuss some research gaps that need to be addressed.

In formulating guidelines, we draw primarily on research, published in this Special Issue, that provides information on reference sites (Fynbos Biome: Sieben and Reinecke, 2008-this issue), the impacts of alien clearance on vegetation recovery (Fynbos Biome: Blanchard and Holmes, 2008-this issue; Reinecke et al., 2008-this issue; Savanna and Grassland Biomes: Beater et al., 2008-this issue; Morris et al., 2008-this issue), seed banks (Fynbos Biome: Fourie, 2008-this issue; Vosse et al., 2008-this issue) and alien recruitment dynamics (Savanna and Grassland Biomes: Witkowski and Garner, 2008-this issue). Additional information is also presented on the impacts of a major flood on patterns of alien plant distribution (Savanna Biome: Foxcroft et al., 2008-this issue), the impacts of different alien slash fires on seed germination (Fynbos Biome: Behenna et al., 2008-this issue) and an assessment of an active restoration experiment (Fynbos Biome: Pretorius et al., 2008-this issue). The drought resistance of key Fynbos Biome riparian scrub species is investigated (Swift et al., 2008-this issue). Finally, the extent of riparian alien clearing, and the costs and benefits of this clearing countrywide, are investigated (Marais and Wannenburgh, 2008-this issue).

2. Synthesis of latest research: Fynbos Biome

2.1. What has been achieved in terms of ecosystem repair?

In the Western Cape, research was focussed on the worst-case scenarios: closed-stand invasions (>75% aerial cover) where post-clearance problems were most likely. *Acacia mearnsii* was the dominant invasive alien species in most reaches. In the Eastern Cape, dense to closed stands of predominantly *Acacia longifolia* were studied. In this research, it was assumed that ecosystem functioning is restored where vegetation post-clearance resembles an uninvaded, reference site in terms of vegetation structure (e.g. growth form composition), species composition and aerial cover.

Following closed-stand invasions by *A. mearnsii*, 44% of the cleared sites supported vegetation with growth form and species composition comparable to uninvaded reference sites (Blanchard and Holmes, 2008-this issue). Interestingly, in relation to these two variables, the same plots did not always align to the reference condition. For example, 95% of plots cleared by the “Fell & Remove” treatment were successfully restored in terms of growth form composition, but only 59% had a species composition within the range of the reference plots. In nearly all variables measured, the “Fell & Remove” treatment surpassed the other two clearing treatments investigated (Blanchard and Holmes, 2008-this issue). On the other hand, in the “Fell Only” treatment, only 10% of plots had growth form composition restored, yet 63% were considered similar to the reference condition in relation to species composition. This seemingly-contradictory result may be explained by the alien slash inhibiting plant establishment, growth and the restoration of vegetation structure, yet allowing typical riparian species to recolonize in low numbers. This treatment is thus on a trajectory to recovery, but full recovery will take more time than the 2–10 years sampled in this study. The “Fell & Burn” treatment was intermediate to the other treatments in restoration of vegetation structure, but had the most altered composition with only 24% of plots considered similar to the reference. In this treatment, graminoids – particularly grasses – were promoted. Alien slash fires may eliminate soil-stored seed banks through unnaturally high soil temperatures (Holmes, 1989; Cilliers et al., 2004) thus changing community composition in favour of quick-colonizing, wind-dispersed species. An alternative explanation for the relatively-poor performance of this clearing treatment, is that fire promotes germination in heat-stimulated seed banks, such as those of the alien acacias (Jeffery et al., 1988; Behenna et al., 2008-this issue), which in turn would trigger a follow-up clearance response of blanket herbicide spraying that would indiscriminately kill all dicotyledonous species, indigenous and alien alike. It was not possible to access data to confirm the latter scenario.

The influence of time since clearance on vegetation recovery was investigated by first dividing the data set into those sites cleared two to five and six to ten years ago (Blanchard and Holmes, 2008-this issue). Indigenous vegetation cover increased over time, but there was no overall change in species richness. For “Fell Only” and “Fell & Remove” sites, older cleared sites more closely aligned to the reference sites in terms of species composition, but this pattern was less evident for the “Fell & Burn” treatment. This confirms that unburnt, cleared sites are on a trajectory towards recovery, but for the burnt treatment sites, recovery may be arrested, and in some cases additional restoration interventions may be required to restore vegetation structure.

Active restoration, by sowing indigenous seeds after a “Fell & Burn” treatment in 1998, did increase species and structural diversity (Pretorius et al., 2008-this issue). However seven years later, alien *A. mearnsii* again dominated the restoration site, as follow-up weeding had not been continued beyond the first follow-up in 1999. Further sampling after a subsequent fire in 2006 indicated that some of the sown indigenous species survived by resprouting (e.g. *Brabejum stellatifolium*); ericoid shrubs, forbs and graminoids survived through seedling recruitment, but serotinous proteoid shrubs (e.g. *Leucadendron salicifolium*) failed to recruit from seed. The alien *Acacia* survived fire both by resprouting and recruiting from seed. Alien *Acacia* seedling recruitment was lower post-fire in plots that had received a sowing treatment in 1998, indicating some potential of indigenous species to suppress the aliens. Active restoration of riparian areas may be used to improve indigenous vegetation recovery potential at severely-impacted sites and furthermore, assists in suppressing woody alien recruitment. However, it is important that any active plant re-introduction is coupled with regular alien follow-up removals in order to secure the benefits into the future.

2.2. Have thresholds to recovery been passed?

No new results on abiotic thresholds have emerged, but earlier work indicated that stable slopes may be required for the establishment of characteristic fynbos riparian scrub species (Galatowitsch and Richardson, 2005). Unpublished work (C. Boucher, Stellenbosch University) indicated that alien tree stands in foothill river reaches may accumulate sediments and alter river geomorphology. Such features could inhibit post-clearance recovery if the indigenous seed bank is buried too deep below the sediments for successful germination, or if the sediments are unstable and thus unsuitable for colonization by desirable riparian scrub species.

The soil seed bank studies confirmed that many of the characteristic riparian closed-scrub species are not represented (Fourie, 2008-this issue; Vosse et al., 2008-this issue). Thus a biotic threshold to recovery would be passed in degraded catchments where riparian vegetation has been eliminated. Non-soil seed bank species include the dominant riparian scrub trees (e.g. in the Western Cape: *B. stellatifolium*, *Metrosideros angustifolia*) and serotinous shrubs (e.g. *L. salicifolium*). *B. stellatifolium* and *M. angustifolia* are ubiquitous in Western Cape riparian zones (Galatowitsch and Richardson, 2005) and are tolerant of a wide range of summer water availability (Swift et al., 2008-this issue), further indicating their suitability for restoration projects. Herbaceous and low-shrub growth forms dominate the seed bank in both the Western and Eastern Cape (Fourie, 2008-this issue; Vosse et al., 2008-this issue). The most frequently-occurring species comprise herbaceous and small–medium shrub species of fynbos affinity, with families such as Poaceae, Cyperaceae and Asteraceae prominent. Seed bank composition was clearly defined by the moisture regime (wet or dry bank lateral zone), longitudinal position (mountain stream or foothill), and river catchment area, with some rivers showing a greater diversity of species associated with the different riparian zones than other rivers (Vosse, 2007). The wet bank zone was dominated by riparian species, with the families Cyperaceae and Poaceae prominent, whereas the dry bank zone had a higher richness and diversity that comprised of mainly fynbos species (including both terrestrial and wetland-adapted species). The soil seed bank of riparian corridors is thus important in regenerating vegetation of the wet bank lateral zone and the understorey of the dry bank lateral zone following disturbance.

The soil seed bank composition in closed alien stands was less species-rich, dominated by herbaceous species, and with alien species more frequent and dominant (Fourie, 2008-this issue; Vosse et al., 2008-this issue). Nevertheless, indigenous riparian graminoids and a few shrub species persisted at invaded sites, although species composition was much more variable and unpredictable. The results imply that vegetation regenerating from the seed bank after clearing will comprise herbaceous, short-lived species that are mainly non-resprouters.

In sites receiving a “Fell & Burn” treatment, the seed bank is likely to have been depleted further (owing to the combined effects of a hot slash fire and post-fire herbicide application; Blanchard and Holmes, 2008-this issue). This treatment is more likely to exceed a biotic threshold compared to the others, and may require active restoration (by sowing or planting nodes of later-seral riparian scrub species) following clearance. Reinecke et al. (2008-this issue) indicated good riparian recovery following pine compared to acacia removal for similar treatments.

2.3. What is achievable and what could be improved?

Recovery of natural vegetation post-alien clearance, in the majority of alien-invaded foothill and mountain stream reaches of the Fynbos Biome, is achievable and should be the target. Exceptions are:

(i) Where long-standing, closed alien acacia stands are cleared in a degraded and transformed catchment and indigenous propagule sources are lacking in the upstream and surrounding area.

(ii) Where a closed alien acacia stand receives a "Fell & Burn" alien-clearing treatment.

It is recommended that managers consider using the "Fell & Remove" treatment in all cases of dense to closed alien stand clearing along rivers. Where it is impractical to remove slash, it should be stacked away from the riparian zone in areas where small (<1.2 m high), wet season stack burns can be safely carried out. Where possible, stacks should be burned on sandbars in the riverbed, before the onset of the major rains, to avoid damage to surrounding vegetation. An alternative option is to kill large trees standing. From observations in the field and the vegetation survey results, greater care to avoid damaging any indigenous plants should be exercised when clearing vegetation. This applies to both initial felling of indigenous species as well as spraying them with herbicide during follow-up treatments. It would thus appear that more effort is required in training and supervising the contract teams to minimize destruction of indigenous species.

Where the goal is to restore an indigenous stand of riparian vegetation, active restoration can potentially improve recovery. This should be considered in degraded catchments with few remaining indigenous propagule sources to drive the recovery, and also where damage had been caused by a severe fire or excessive use of herbicides. Following alien clearance and fire, riparian shrubs and trees either re-establish early or else the vegetation remains largely herbaceous (Reinecke et al., 2008-this issue). Thus a simple survey within the year following fire should indicate if active restoration is required.

2.4. What are realistic goals?

In the majority of invaded mountain stream and foothill river reaches in the Fynbos Biome, a realistic goal is to return the riparian zone to a vegetation stand that is structurally representative of riparian scrub and dominated by indigenous species. This goal is appropriate in that riparian scrub vegetation will best ensure that riparian ecosystem functions are restored, hence improving the ecological state and productivity of the rivers.

For some dense to closed alien stands, it may be an unrealistic goal to restore the vegetation to a pre-invasion reference community (in terms of species composition and diversity) within a short (5–10 years) time frame, especially where slash is left *in situ*. However, once indigenous structural components have re-established and invasive aliens are controlled, diversity and composition are likely to continue to change towards the reference community over a longer time frame.

Lowland flood-plain river reaches in the Fynbos Biome have a long history of degradation and invasion and it is unrealistic to set a goal of restoring riparian zones to some pre-invasion reference condition. Instead, the goals should be set according to the required functions of the riparian zone in the particular area; in other words to rehabilitate the riparian zones to fulfil appropriate ecosystem functions (e.g. bank stabilization, water filtration). Wherever possible, indigenous species should be used in the rehabilitation and invasive alien species removed.

It has been suggested by natural resource managers and researchers that measures other than species composition and richness (using vegetation structure, indicator species and water discharge rates) might be suitable to guide ecosystem repair (Holmes, 2007). Furthermore, for aliens under successful biological control, a more appropriate end point than 100% clearance may be a phased clearance to allow gradual recolonization by indigenous riparian species. This approach could prevent an alternative stable state of secondary invasions developing in response to disturbance by the initial clearance of closed alien stands, but would require careful monitoring of aliens not under biological control as well as a strategy to mobilize clearing after fire.

3. Synthesis of latest research: Grassland and Savanna Biomes

3.1. What has been achieved in terms of ecosystem repair?

Vegetation surveys conducted along the Sabie River in Mpumalanga re-sampled permanent plots of low (<50% aerial cover) and high (>50% aerial cover) invasion intensity in the Grassland and Savanna Biomes that were first sampled a decade ago (Beater et al., 2008-this issue). Some areas were cleared in the late 1990's, prior to the major flooding event in 2000, then three times between 2000 and 2005. The main treatment was "Fell Only", except in areas adjacent to plantations where logs were accessible and removable, and hence "Fell & Remove" was applied. There was considerable overlap in species composition between the higher altitude grassland and lower altitude savanna riparian sites (Beater, 2006). *Eucalyptus grandis* was the dominant alien tree and *Rubus cuneifolius*, *Lantana camara* and *Solanum mauritianum* the dominant alien shrubs. Reference vegetation along this river corridor comprises mainly riparian forest and woodland communities and does not always reflect the composition of the adjacent terrestrial Grassland or Savanna plant communities. The vegetation structure and species composition of the low invasion Grassland and Savanna plots, uncleared in 1996/7, were selected as the reference conditions.

Comparing the datasets between 1996/7 and 2005, total plant species richness increased from 163 species in 1996, to 282 in 2005 (a 42% increase). Mean site species richness (at the 1000 m^2 scale) increased significantly from 24.1 ± 1.0 in 1996 to 44.4 ± 1.5 in 2005 (Beater, 2006). This increase was reflected by all growth forms. However, the greatest total increase was for Categories 1, 2 and 3 invasive alien species, from 20 in 1996/7 to 51 in 2005 (a 61% increase). Overall invasive alien cover was very similar between the years ($30.0 \pm 4.6\%$ in 1996/7 versus $31.9 \pm 3.2\%$ in 2005; Beater et al., 2008-this issue). Closer examination of the data indicated a decrease in the aerial cover of large alien trees and shrubs (>2 m height), and an increase in the aerial cover of the smaller alien trees and shrubs (1–2 m height). The latter comprised both resprouts and young saplings. These results indicate that alien clearance by WfW is succeeding in removing the larger individuals, but not in controlling the regenerating plants and new invasive species which were not prevalent under the canopy shade of *E. grandis*.

A comparison of alien aerial cover before and after clearance, for those plots cleared in 1996/7, allowed the initial effectiveness of the WfW treatments to be determined. Clearing was much more effective in the Grassland (high invasion intensity = 71% reduction, low = 94%) than the Savanna Biome (high = 55% reduction, low = 52%). Hence, considering only the plots cleared in 1996/7, the overall pre-clearance invasion intensity was 62% in the grassland, and WfW clearance in 1996/7 reduced this to 12%. Similarly, the overall pre-clearance invasion was 44% in the savanna, and WfW clearance reduced it to 20%. In addition, the early clearing had a major impact on vegetation structure, with clearing in high invasion grasslands resulting in the alien aerial cover of trees > 5 m in height being reduced from 67% to only 13%. The comparable result in the savanna was a reduction from 28% to 1%.

In 1996/7, the low-density invaded sites were significantly more species-rich than the high-density invaded sites, but this difference was not sustained through to the 2005 survey (Beater, 2006). Nor were any differences from clearing status in 1996 sustained through to 2005. Hence there is progressive homogenisation of species composition over time across the study areas (Beater et al., 2008-this issue).

This is one of the few studies that has assessed both the initial effectiveness of WfW clearing in the mid 1990s, as well as its long-term effects, on alien plant invasion, vegetation structure and the nature of the ground cover. This long-term view has clearly shown that the nature of the alien invasion problem along the Sabie River has changed considerably from the original situation of relatively few large *E. grandis* trees, to one where a large cocktail of alien species have become important, with the density of plants to be cleared increasing dramatically (Beater et al., 2008-this issue). This has implications both for increasing WfW staff training and clearing time commitments.

The 2000 flood event had an estimated 90–200 year return interval (Smithers et al., 2001) and moved a tremendous amount of sediment (Rountree and Rogers, 2004). It is probable that the simultaneous stripping of riparian vegetation and deposition of sediments and propagules by the flood would have reset the vegetation succession to a recolonization phase at many of the permanent study sites, irrespective of prior alien invasion and clearance treatment. Hence many more species, both indigenous and alien, were present in 2005 compared to 1996/7. This event highlights the dynamic nature of riparian ecosystems and the need to prioritise upper catchment reaches and sustain alien-clearing operations, in order to gain long-term control of invasive species and facilitate riparian ecosystem repair downstream.

The relatively infrequent WfW clearing in the upper Sabie River catchment contrasts with the much more frequent clearing performed in the lower catchment in the Kruger National Park (KNP). A reduction by 80% of alien plants and a concomitant increase in indigenous plant densities occurred post-clearance (Morris et al., 2008-this issue). Indigenous herbs, then shrubs, increased the most in transects that were previously-heavily invaded. Alien plant densities, established after the 2000 flood, were relatively low compared to indigenous species, and were associated with specific habitat patches in the river channel (Foxcroft et al., 2008-this issue). Low levels of alien plant establishment inside KNP were attributed to both the earlier pre-flood clearing actions by WfW and the high richness and density of native vegetation. These results show the significance of frequent clearings and follow-ups.

3.2. Have thresholds to recovery been passed?

Based on the Sabie River plot re-sampling study, no threshold to recovery has been passed, as sites were able to recover vegetation structure, richness and diversity in the few years following a major flood event, irrespective of earlier invasion intensity. This applied to both high altitude Grassland Biome and low altitude Savanna Biome sites. Savanna riparian ecosystems are resilient to disturbance by aliens and good natural restoration potential follows alien clearance. However, few of the sites studied had closed-stand alien invasion, so it is not possible to say whether a threshold to recovery would be passed in a situation of more intensive invasion. The presence of indigenous herb and shrub seed banks and propagule sources appears key to initiating ecosystem repair in savanna riparian zones post-alien clearance.

Sites with closed-canopy invasion by *E. grandis* or other invasive alien trees may need some active restoration intervention to re-instate riparian woodland structure and composition post-alien clearance, especially in transformed catchment areas.

3.3. What is achievable and what could be improved?

There is good potential for recovery of indigenous riparian vegetation following alien clearance at sites supporting dense (50–75%) alien invasion, particularly in conservation areas and other areas where disturbance by human activity (e.g. agriculture and livestock grazing) has not been too intense. However, short-term (5–10 years) reductions in alien plant densities did not result from sustained WfW clearing operations at all sites. Aliens that regenerated post-clearance were trees and shrubs, many of which survived by resprouting. This indicates that aliens with resprouting capability, for example *S. mauritianum*, need to be followed-up as a priority, with the quality of clearing (correct cutting and herbicide application) improved to prevent survival by resprouting. Cutting *Solanum* below 18 cm in height resulted in 100% success (total kill), while cutting above 50 cm resulted in 100% recovery by resprouting (Witkowski and Garner, 2008-this issue). It further indicates a need to train clearing teams in the importance of correct clearing techniques. Assessing stem cutting effectiveness, in conjunction with herbicide applications, on other important species would also be very useful in order to improve overall success rates.

More effective control of aliens in the KNP section of the Sabie River, which receives more frequent follow-up clearing of new seedlings and recovering resprouters, strongly suggests the need for more frequent follow-ups in the upper catchment of the river as well (Morris et al., 2008-this issue). Such action would help to prevent the re-establishment of aliens from seed. The KNP study also indicates that greater attention is required after above-average rainfall years, as alien densities tend to increase to a much greater extent than in low rainfall years.

Considerable flexibility will be needed in planning alien plant control operations in riparian zones of the Savanna and Grassland Biomes. Alien plants respond rapidly to disturbance,

Table 2
Factors influencing the recovery potential of alien-invaded riparian zones, based on research findings reported in this Special Issue

Category	Factors that influence recovery
Abiotic environment	• Major flood event
	• Headcut erosion and channelization [a]
Impact of alien plants	• Density of alien stand
	• Dominant alien species
	• Number of alien species
	• Extent of invasion (in wider catchment)
Impact of alien clearance	• Initial clearing method (especially slash removal and fire)
	• Follow-up clearing method
	• Training level of contract teams
Active restoration	• Sowing post-fire to improve vegetation structure and composition
	• Sowing post-fire to suppress alien re-growth

[a] S. Fourie, unpublished data in Holmes (2007).

for example a major flood event or a high rainfall year, and clearing schedules need to be updated to prevent the aliens from re-establishing, reproducing and dispersing propagules downstream. Owing to the high frequency of natural perturbations in riparian ecosystems, it is also recommended, as an overall strategy, that control operations in larger catchments commence upstream and move downstream, in order to minimize re-invasion of downstream areas. This requires communication among managers and regular regional progress meetings.

3.4. What are realistic goals?

In the Grassland and Savanna Biomes, riparian ecosystems are relatively resilient to the impacts of invasion, and alien clearance alone can lead to the recovery of indigenous vegetation structure and diversity. Impacts of the 2000 large flood event highlight that riparian ecosystems are naturally highly dynamic and that adaptive management will be required to maintain control of invasive alien species in the long-term. For sites with medium to dense alien invasions, a realistic goal is to restore riparian vegetation structure and composition, provided that sufficient and effective alien follow-up removals are done. For closed-stand invasions of tall *E. grandis* trees, for example, ecosystem functioning may be restored through alien clearing, but active restoration of riparian tree and shrub components may be required in order to restore vegetation structure and composition within a reasonably short time frame and thus facilitate resistance to secondary alien species' invasions.

4. Management guidelines

Implicit in the rationale behind our research into ecosystem repair targets, is the assumption that indigenous vegetation recovery is a fundamental requirement for the long-term control of invasive species. It is generally assumed that, as a minimum, non-invasive vegetation that can fulfil basic ecological functions must be re-instated. Thus, management of invasive plants and ecosystem repair are inextricably linked. The field studies reported in this Special Issue are not sufficient to answer all the questions relating to ecosystem repair targets. However, they do provide new and valuable insights into the impacts of aliens, alien clearance and other factors on riparian vegetation recovery that enable us to provide some guidance on realistic ecosystem repair targets. Although the riparian ecosystems studied in Fynbos, Grassland and Savanna Biomes are very different many of the findings from the specific studies have general applicability (Table 2). Many of these factors can be addressed through appropriate management.

4.1. Restoration frameworks

Worldwide, ecologists and natural resource managers are grappling with the complex challenge of how to best control

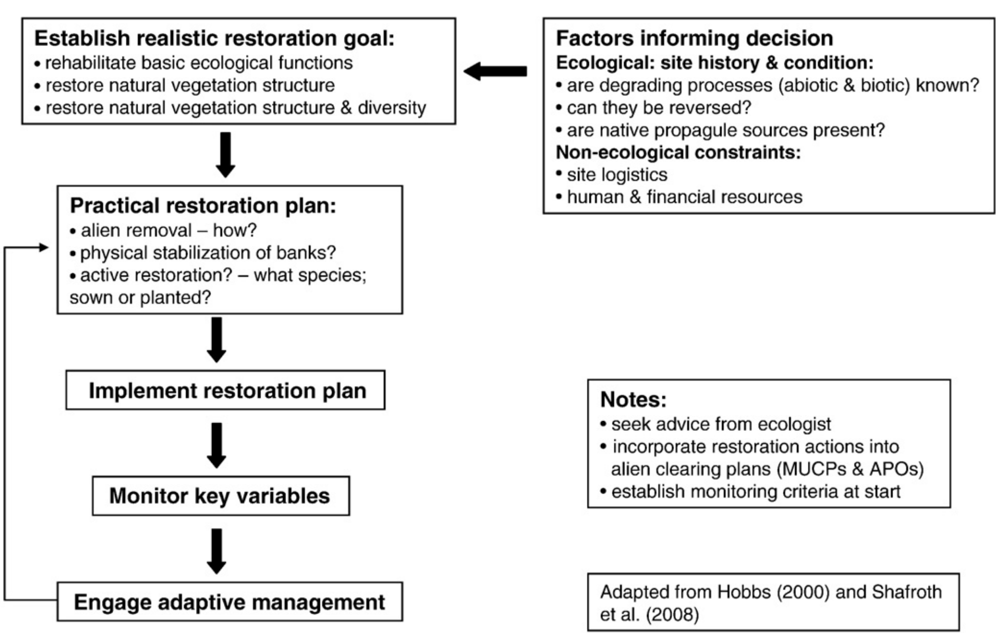

Fig. 2. Conceptual framework for ecosystem repair in alien-invaded riparian zones (adapted from Hobbs 2000 and Shafroth et al. in press).

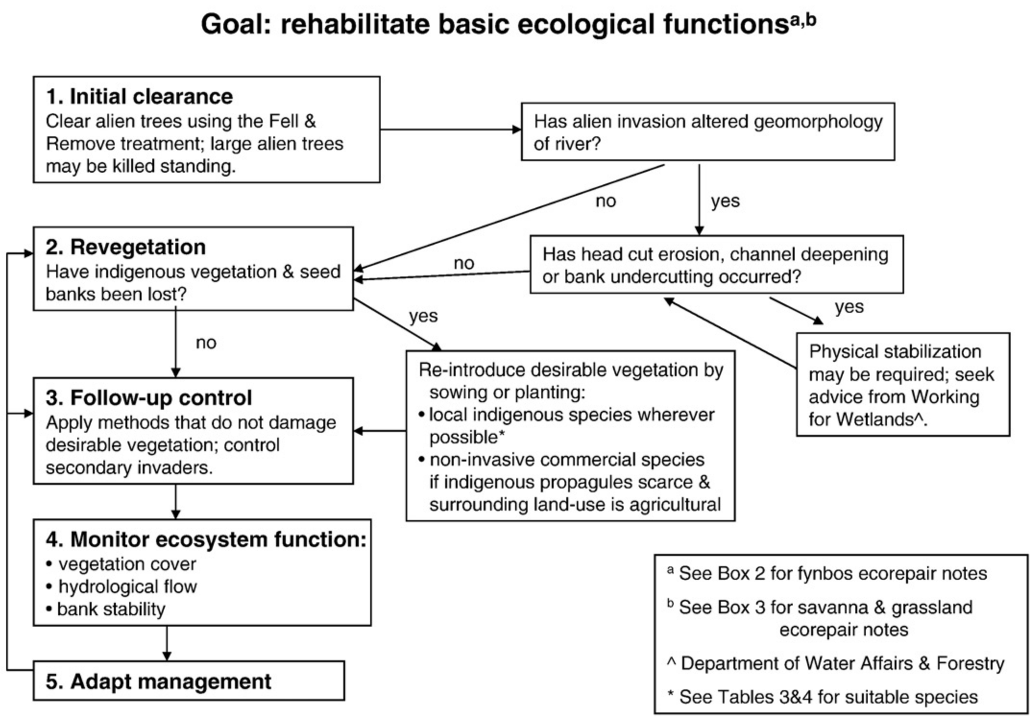

Fig. 3. Practical decision framework for restoring ecosystem functioning in alien-invaded riparian zones.

invasive alien plants while simultaneously promoting ecosystem repair and delivering the required ecosystem services to humans. Many factors: ecological, economic and socio-political, influence decisions on the ground and realistic repair targets must incorporate all of these factors. While ecological research can assist in improving our understanding of invasion and restoration processes, the findings need to be incorporated into conceptually, practically and financially-realistic frameworks to assist restoration in practice (Hobbs, 2007).

4.1.1. Conceptual restoration framework

In considering frameworks for restoring invaded riparian ecosystems in South Africa, many variables operate to make this a daunting task. It is helpful to provide an overarching

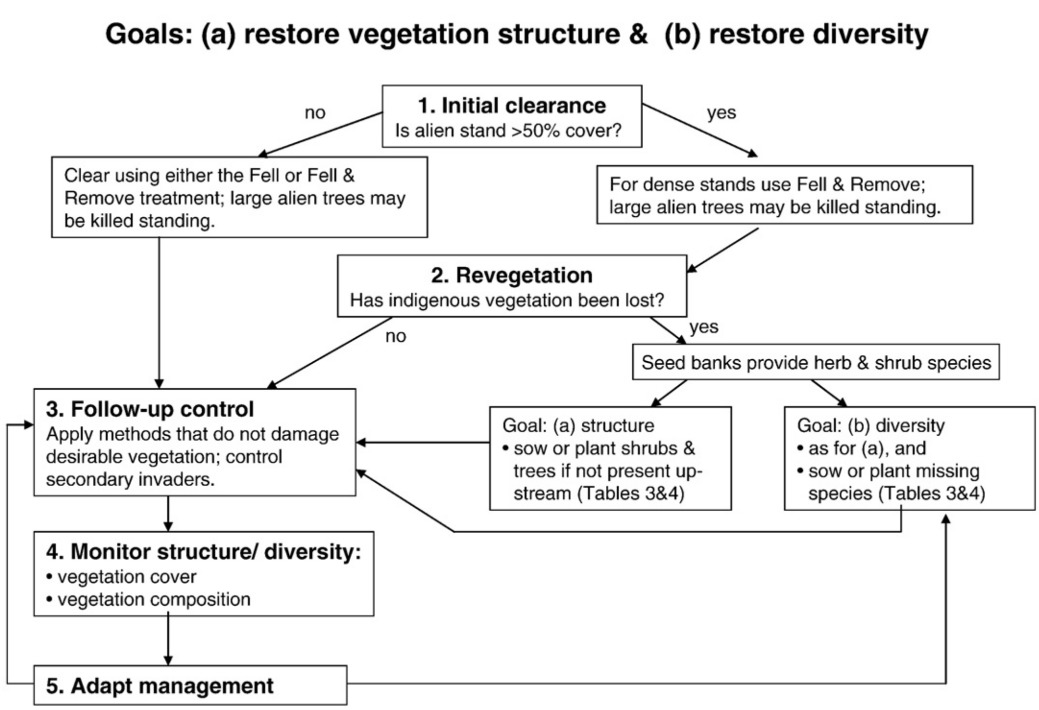

Fig. 4. Practical decision framework to restore vegetation structure and diversity in alien-invaded riparian zones.

Box 2

Fynbos ecosystem repair notes to accompany practical decision frameworks

1. Initial clearance

- For dense to closed woody alien stands it is best to fell and remove large-diameter wood (>50 mm) from the riparian zone. This wood may be sold to offset some of the clearance costs, or else should be burnt in stacks when the soil is wet to minimize soil and seed bank damage. Where there is no secondary industry market, large-diameter (>250 mm) trees should be killed standing (ring-barked or frilled). For aliens under substantive biological control, consider phased removal.
- For light to medium-density stands, slash may be left to decompose *in situ* or burn in the next fire without negatively impacting the recovery potential of the site. However large-diameter trees should be killed standing to keep biomass off the soil surface.

2. Revegetation

- If some indigenous vegetation is present prior to alien clearance, soil seed (and propagule) banks supplying indigenous herbaceous and shrub understorey species are likely to be present. If there was little evidence of indigenous vegetation pre-clearance, seed banks may still be present provided that there was no other habitat disturbance (such as ploughing) or long-term dense invasion (exceeding 2 fire-cycles).
- However, if a severe fire has gone through the area (with evidence of burnt soil organic matter or subsequent soil erosion) seed banks will have been severely depleted.
- Where indigenous seed banks have been depleted, the site requires active revegetation. To restore ecosystem functioning, the minimum requirement is bank stability and soil surface erosion control. Thus a mix of local pioneer, understorey (herb and shrub) species should be sown (see Table 3). Where seed of local indigenous species is not available or insufficient, commercial non-invasive grasses may be used in an area that is primarily agricultural or disturbed. In the Western Cape, potential species are annuals such as sterile Italian Rye Grass (*Lolium perenne*) and commercial oats (*Avena sativa*). In the Eastern Cape *Digitaria eriantha* may be used.
- In terms of restoring structure, if pockets of indigenous scrub persist along the river – within 200 m or upstream of the site – then these species will recolonize over time. If there are very few pockets of remaining scrub in the catchment, then active planting of scrub species is recommended, especially if the surrounding terrestrial vegetation is degraded and cannot supply pioneer shrub species.
- Riparian scrub species may be established from rooted cuttings or seedlings transplanted in the field, or for some Western Cape species (e.g. *B. stellatifolium*) directly from fruits placed on site. However, early results suggest that unrooted truncheons have limited success (for species list see Table 3).
- Sowing should be done directly onto bare ground, with the seed lightly raked into the soil or covered by light woodchip mulch. If done after initial clearance, the establishing vegetation has potential to partially suppress alien recruitment and reduce follow-up costs. Seed should be sown in autumn in the Western Cape, and either early autumn or early spring in the Eastern Cape.
- Planting is best done under similar conditions to the sowing treatment, although some scrub species may establish better in the presence of sheltering herbaceous species. In the Eastern Cape grasses are better planted in spring.

3. Follow-up control

- Only methods that do not damage recovering indigenous species should be used: e.g. hand-pull, cut and stump treat. If foliar herbicide spraying has to be done, then it must be on a wind-free day with all indigenous species first covered in a protective cone or similar device.
- Special care should be taken to identify aggressive secondary invader species and control these timeously to allow time for indigenous vegetation recovery.

4. Monitor ecosystem recovery

- *Geomorphology*: simple measures such as channel depth and width (using permanently marked locations)
- *Soil erosion*: e.g. hammer steel pins into bank and measure soil loss or gain
- *Vegetation cover*: fixed point photography, permanent plots to measure alien, indigenous and ground cover
- *Vegetation structure*: permanent plots to monitor growth form density; including kill rate of aliens
- *Vegetation composition*: permanent plots to monitor species presence and cover.

5. Adaptive management

- Assess monitoring results relative to ecosystem repair targets and where necessary revisit methods and adapt management.

conceptual framework (Fig. 2) within which more specialized practical frameworks may be formulated. Thus it is appropriate that national goals and targets are outlined, but from this it is essential to develop more regional and site-specific targets with input from local managers. Ecological variables that influence practical restoration frameworks include: biome and vegetation type, river order, invasion history (species, intensity and time) and surrounding land-use/extent of transformation (Table 2).

The appropriate restoration target for a site should be informed by ecological factors, such as extent of degradation by aliens and availability of indigenous propagules, as well as by non-ecological factors such as the desired land-use for the area and availability of resources (human and financial). There is a good economic case to be made for active restoration at some riparian sites cleared of closed-stand invasions, as experience has shown that after many follow-up clearing operations, at great expense, ecosystem repair

Box 3

Grassland and savanna ecosystem repair notes to accompany practical decision frameworks

1. Initial clearance (also see Euston-Brown et al., 2007)

- For dense to closed woody alien stands, fell and remove large-diameter wood (>50 mm) from the riparian zone. This wood may be sold to offset some of the clearance costs, or else stacked and left to decompose. Where there is no secondary industry market, large-diameter (>250 mm) trees should be killed standing (ring-barked or frilled). For aliens under effective biological control, phased removal should be considered.
- For light to medium-density stands, slash may be left to decompose *in situ*. Woody species must be cut low enough to prevent resprouting. However large-diameter trees should be killed standing to keep biomass off the soil surface to lower the risk of damaging fires in regenerating riparian woodland.

2. Revegetation

- If some indigenous vegetation is present prior to alien clearance, soil seed (and propagule) banks supplying indigenous herbaceous and shrub species are likely to be present. If there was little evidence of indigenous vegetation pre-clearance, seed banks may still be present provided that there was no other habitat disturbance (such as ploughing) or long-term dense invasion (e.g. wattle or *E. grandis*).
- Where indigenous seed banks have been depleted (e.g. after a 30 year dense aliens or following a severe fire) and the surrounding catchment is transformed, the site requires active revegetation. To restore ecosystem functioning, the minimum requirement is bank stability and soil surface erosion control. Thus grass or understorey (herb and shrub) species should be sown or planted. Campbell (2000) compiled guidelines for using grass to cover soil after alien plant control (including species and planting guidelines). Although aimed at terrestrial ecosystems, these techniques can be applied to highly-transformed riparian zones. Grasses broadcast sown or planted help to suppress recruitment of aliens (e.g. wattle) from the seed bank while providing cover to bare soil. Grasses sown in rows or terraces may assist in halting surface erosion on slopes. Where seed of local indigenous grass is not available or insufficient, commercial non-invasive grasses may be used in an area that is primarily agricultural or disturbed.
- In terms of restoring structure, if pockets of riparian woodland persist along the river – within 200 m or upstream of the site – then these species will recolonize over time. If there are very few pockets of remaining indigenous trees in the catchment, then active planting of tree species is recommended, particularly following dense wattle or *Eucalyptus* invasion.
- Planting of trees and shrubs should be done at the start of the wet season (November), from seeds (scarified or prepared in order to allow rapid germination) or using pre-grown transplanted seedlings (~200 mm tall) in forestry plugs (for species list see Table 4).
- Sowing and/or planting should be done after a thorough initial clearing treatment and the re-introduced plants tended (weeds removed around them) during follow-ups and during the first year until well established.

3. Follow-up control

- Only methods that do not damage recovering indigenous species should be used: e.g. hand-pulling, cut and stump treat. If foliar herbicide spraying has to be done, then it must be on a wind-free day with all indigenous species first covered in a protective cone or similar device.
- Special care should be taken to identify aggressive secondary invader species and control these timeously (before seed-set) to allow time for indigenous vegetation recovery.

4. Monitor ecosystem recovery

- See Box 2.

5. Adaptive management

- Assess monitoring results relative to ecosystem repair targets and where necessary revisit methods and adapt management.

Table 3
Examples of relatively-common species to use in restoring riparian vegetation in the Fynbos Biome (SSB = soil seed bank; CSB = canopy seed bank; none = no seed bank; ? = uncertain)

a) Winter rainfall fynbos areas

Species	Growth form	Regeneration mode	Propagation method		
			Seed	Split	Cutting
Wet bank					
Calopsis paniculata	Herb–restio	Reseeder SSB	√	√	
Elegia capensis	Herb–restio	Resprouter SSB	√	√	
Erica caffra	Shrub	Reseeder SSB	√		
Isolepis prolifer	Herb–sedge	Reseeder SSB		√	
Juncus capensis	Herb–rush	Reseeder SSB		√	
Juncus lomatophyllus	Herb–rush	Reseeder SSB		√	
Pennisetum macrourum	Herb–grass	Reseeder SSB	√	√	
Salix mucronata	Shrub	Resprouter ?			√
Dry bank					
Anthospermum aethiopicum [a]	Shrub	Reseeder SSB	√		
Berzelia lanuginosa	Shrub	Reseeder CSB	√		√
Brabejum stellatifolium	Shrub–tree	Resprouter none	√		√
Brachylaena neriifolia	Shrub–tree	Resprouter ?	√		√
Diospyros glabra	Shrub	Resprouter none	√		√
Leucadendron salicifolium	Shrub	Reseeder CSB	√		
Metrosideros angustifolia	Shrub–tree	Resprouter ?			√
Morella serrata	Shrub	Resprouter ?			√
Pentaschistis pallida	Herb–grass	Reseeder SSB	√		
Psoralea pinnata	Shrub	Reseeder SSB	√		
Rhus angustifolia	Shrub	Resprouter ?	√		√
Tribolium uniolae [a]	Herb–grass	Reseeder SSB	√		

b) All-year rainfall grassy Fynbos areas

Species	Growth form	Propagation method		
		Seed	Split	Cutting
Wet bank				
Anthospermum herbaceum	Herb–forb			√
Blechnum sp.	Herb–fern	√		
Carpha glomerata	Herb–sedge	√		
Chironia baccifera	Shrub	√		√
Cliffortia graminea	Shrub		√	√
Cliffortia strobilifera	Shrub			√
Conyza ulmifolia	Herb–forb	√		
Cyperaceae spp.	Herb–sedge	√	√	
Cyperus textilis	Herb–sedge		√	
Elegia asperifolia	Herb–restio	√		
Ficinia capillifolia	Herb–sedge	√	√	
Ficinia oligantha	Herb–sedge	√	√	
Fuirena sp.	Herb–sedge	√	√	
Tristachya leucothrix	Herb–grass	√	√	
Helichrysum epapposum	Herb–forb	√		√
Isolepis cernua	Herb–sedge	√	√	
Isolepis prolifer	Herb–sedge	√	√	
Miscanthus capensis	Herb–grass	√		
Rumohra adiantiformis	Herb–fern	√		
Dry bank				
Alloteropsis semialata	Herb–grass	√	√	
Anthospermum herbaceum	Herb–forb			√
Berzelia commutata	Shrub	√		
Carpha glomerata	Herb–sedge	√		
Chrysanthemoides monilifera	Shrub	√		
Erica brownleeae	Shrub	√		
Halleria lucida	Shrub	√		
Helichrysum cymosum	Shrub	√		√
Helichrysum petiolare	Shrub	√		√
Merxmuellera cincta	Herb–grass	√		
Passerina filiformis	Shrub	√		√
Pelargonium cordifolium	Shrub	√		√
Phylica axillaris	Shrub	√		√
Polygala virgata	Shrub	√		
Psoralea pinnata	Shrub	√		
Rapanea melanophloeos	Tree [b]	√		√
Rhus sp.	Shrub/tree	√		
Senecio chrysocoma	Herb/shrub	√		
Senecio rigida	Herb/shrub	√		
Themeda triandra	Herb–grass	√	√	

Potential propagation methods, as recommended by local horticulturists, are indicated (√).

[a] Common local grass and shrub species from surrounding fynbos vegetation may be added to seed mixes in order to boost initial vegetation cover.

[b] Other tree species can be re-introduced in special situations, e.g. area of high conservation value, to speed up natural recovery.

has yet to begin (Marais and Wannenburgh, 2008-this issue). Until alien invasions are brought under control, the economic benefits of increased water yields will not accrue. Essentially there are three broad ecosystem repair goals for riparian zones, listed in an increasing order of restoring ecological integrity:

- *Rehabilitate basic ecological functions*: e.g. recover stream flow or erosion control. An important research objective (outside the scope of this Special Issue) is to establish the ecological flows required to maintain river and riparian functioning (King and Brown, 2006). In some catchment areas alien vegetation control, either alone or accompanied by appropriate revegetation actions, may achieve more natural hydrological and geomorphological functioning of the river. By contrast in catchments with large-scale impoundments or water abstraction, restoring natural hydrological functioning may not be feasible and instead the goal should relate to improving current hydrological flows.
- *Restore natural vegetation structure*: reduce the density of alien plants such that sufficient indigenous vegetation remains, or is restored, to ensure that the required ecological functioning is feasible. This requires adaptive (and long-term) management appropriate for a particular area. One important factor to consider should be the status of biological control for the alien species in the area. Where substantial

reduction in density is confidently predicted, expensive and potentially damaging mechanical measures may not be required.

- *Restore natural vegetation structure and diversity*: appropriate goal for conservation areas and catchments where areas of intact natural vegetation persist; requires aliens to be controlled to a maintenance level and processes re-instated that facilitate recolonization by indigenous species.

As mentioned above, alien control and restoration are closely linked, thus it is important to align restoration frameworks with the existing alien-clearing strategies and policies of WfW. The WfW Strategic Planning Policy (Anon, 2007) sets out the national policy on strategic planning for control of invasive alien plants. The priorities as outlined in the document align well with optimising ecosystem repair goals at national and regional scales. The internal WfW "Self-Assessment Standards" provide the framework for project operational planning within the regional and area strategic plans.

4.1.2. Practical restoration frameworks

Most of the research in this Special Issue focussed on mountain stream or foothill segments of rivers traversing landscapes that retain some intact natural vegetation. However, many of South Africa's main stem rivers traverse transformed agricultural lands in the lowlands, are in poor condition and are highly threatened (Nel et al., 2007). In the case of rivers transformed over long periods, it may be more appropriate to re-instate some desirable riparian ecosystem function, such as the temporary stabilization of banks, rather than trying to restore some pre-invasion reference condition, which may be unknown (Richardson et al., 2007).

4.1.2.1. Management tools. In many practical restoration frameworks, the WfW norms, treatments and herbicide policies will be appropriate. Where habitat-specific tools have been developed, for example "Clearing Protocols for Mesic Savannas and Sweet Grassveld" (Euston-Brown et al., 2007), these should also be used to guide preliminary ecosystem repair. However, as these tools were developed primarily to maximise alien plant reduction, there are some instances where an ecosystem repair goal may require a deviation from these approaches. For example, where the goal is to restore natural riparian vegetation structure following the clearance of an old, dense alien stand, it will be very important to protect any establishing indigenous plants (as well as aquatic organisms) from herbicide drift, as these species may be scarce but nevertheless form the basis for the restoration. Therefore the follow-up treatment method should change from foliar herbicide application to hand-pull or cut and stump treatment (depending on alien species, size and density), in order to lower the risk of indigenous plant death. The change in treatment method could have a cost implication, but the benefit in protecting indigenous species could obviate the need for active restoration (e.g. tree and shrub sowing or planting) at possibly greater expense.

Decision trees designed for the Fynbos Biome were found to apply well to Grassland and Savanna Biome riparian areas as well (Figs. 3, 4), despite their different hydrological patterns and phytogeographical affinities. Thus the same decision trees may be used for all three biomes, with differences in detail outlined in accompanying text boxes (Boxes 2, 3).

Table 4
Examples of woody species potentially suitable in restoring heavily-impacted riparian sites in the Grassland and Savanna Biomes of Mpumalanga (from the low invasion uncleared "reference" plots in 1996/7 (Garner 2006)

Species	Growth form	Frequencies (number/5 plots) Grassland	Savanna
Euclea crispa	Shrub	3	2
Combretum kraussii	Tree	1	3
Clutia affinis	Shrub	4	1
Keetia gueinzii	Liana	1	0
Cliffortia nitidula	Shrub	2	0
Buddleja salviifolia	Shrub [a]	2	0
Syzygium cordatum	Tree	0	1
Apodytes dimidiata	Tree	0	3
Tricalysia capensis	Shrub	0	1
Acacia ataxacantha	Tree [a]	0	4
Acacia robusta	Tree [b]	–	–

Notes on propagation of many of these species are included in Schmidt et al. (2002).

Additional tree species that can be used include: *Ekebergia capensis*, *Harpephyllum caffrum*, *Protorhus longifolia*, *Anthocleista grandiflora*, *Bridelia micrantha*, *Breonadia salicina*, *Pittosporum viridiflorum*, *Ficus sur*, *Celtis africana*, *Nuxia floribunda* (higher altitudes) and the shrubs *Diospyros whyteana* and *Rhamnus prinoides* (M. Lotter pers. comm.).

[a] Most favoured species.

[b] For sites closer to the Kruger National Park.

Within a biome, there will also be differences according to site history, extent of transformation in the catchment and future land-use. Thus the decision trees and restoration notes should be used to draw up individual site-specific restoration plans. Differences will apply in relation to recommended species to use in active restoration programmes. Tables of suitable species (Tables 3, 4) have been provided for the different biomes as a broad guideline. However, in all cases of indigenous plant re-introduction, it is important that local species and gene pools are used in order to prevent possible hybridization and loss of genetic integrity in ecosystems.

5. Conclusions

Research results reported in this Special Issue indicate that removal of aliens alone in most cases improves ecosystem integrity and facilitates restoration of indigenous riparian vegetation structure and functioning, lending further support to the ecological rationale for the WfW programme. Different outcomes relating to clearing treatment indicate that in densely-invaded areas, the goal of restoring indigenous vegetation is most likely to be met if alien trees are felled and the large wood removed from the riparian zone. Furthermore, effectiveness depends upon careful implementation of this treatment, including height of cutting and protection of surviving adult indigenous species. At long-invaded sites, where indigenous recruitment is poor after initial clearance, active restoration can facilitate recovery and potentially may reduce alien follow-up costs.

In order to promote the case for active restoration at long-invaded sites, future research should investigate the long-term effectiveness of sowing and planting treatments as well as the costs and benefits of those treatments versus alien clearance alone. A combined assessment of the ecological, social and economic benefits of riparian ecosystem repair at various scales would greatly assist in strategic planning. At the operational level, research to better understand effectiveness of cutting heights and herbicide applications to different alien species would assist in reducing alien recruitment and as a result promote indigenous vegetation recovery. We also need to investigate how to make better use of biological control and how to integrate this form of control more effectively within the clearing and restoration regimes.

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References

Anon, 2007. The Working for Water Programme Strategic Plan 2008-2012. The Working for Water Programme, Department of Water Affairs and Forestry, pp. 15.

Beater, M.M.T., 2006. Impacts of Invasive Alien Plant Clearing on Riparian Vegetation Recovery Along Riverine Corridors in Mpumalanga, South Africa. University of the Witwatersrand, Johannesburg, MSc dissertation.

Beater, M.M.T., Garner, R.D., Witkowski, E.T.F., 2008. Impacts of clearing invasive alien plants from 1995 to 2005 on vegetation structure, invasion intensity and ground cover in a temperate to subtropical riparian ecosystem. South African Journal of Botany 74, 495–507 (this issue). doi:10.1016/j.sajb.2008.01.174.

Behenna, M., Vetter, S., Fourie, S., 2008. Viability of alien and native seed banks after slash and burn: effects of soil moisture, depth of burial and fuel load. South African Journal of Botany 74, 454–462 (this issue). doi:10.1016/j.sajb.2008.01.179.

Blanchard, R., Holmes, P.M., 2008. Riparian vegetation recovery after invasive alien tree clearance in the Fynbos Biome. South African Journal of Botany 74, 421–431 (this issue). doi:10.1016/j.sajb.2008.01.178.

Blignaut, J.N., Marais, C., Turpie, J.K., 2007. Determining a charge for the clearing of invasive alien plant species to augment water supply in South Africa. Water South Africa 33, 27–34.

Campbell, P.L., 2000. Rehabilitation recommendations after alien plant control. Plant Protection Research Institute Handbook No. 11. Agricultural Research Council, Hilton, pp. 32–45.

Cilliers, C.D., Esler, K.J., Boucher, C., 2004. Effects of alien plant management and fire on soil seed banks and regeneration in the Cape Peninsula National Park, South Africa. South African Journal of Botany 70, 705–712.

Cullis, J.D.S., Gorgens, A.H.M., Marais, C., 2007. A strategic study of the impact of invasive alien plants in the high rainfall catchments and riparian zones of South Africa on total surface water yield. Water SA 33, 35–42.

Dye, P., Jarmain, C., 2004. Water use by black wattle (*Acacia mearnsii*): implications for the link between removal of invading trees and catchment streamflow. South African Journal of Science 100, 40–44.

Euston-Brown, D., Rathogwa, M., Richardson, D.M., 2007. Development of a clearing protocol based on ecological criteria for mesic savannas and sweet grassveld for the Working for Water Programme. Unpublished report. The Working for Water Programme, Department of Water Affairs and Forestry Cape Town.

Fourie, S., 2008. Composition of the soil seed bank in alien-invaded grassy fynbos: potential for recovery after clearing. South African Journal of Botany 74, 445–453 (this issue). doi:10.1016/j.sajb.2008.01.172.

Foxcroft, L.C., Parsons, M., McLoughlin, C.A., 2008. Patterns of alien plant distribution in a river landscape following an extreme flood. South African Journal of Botany 74, 463–475 (this issue). doi:10.1016/j.sajb.2008.01.181.

Galatowitsch, S.M., Richardson, D.M., 2005. Riparian scrub recovery after clearing of invasive alien trees in headwater streams of the Western Cape. Biological Conservation 122, 509–521.

Garner, R.D., 2006. Vegetation response to clearing of exotic invasive plants along the Sabie River, South Africa. MSc Dissertation, University of the Witwatersrand, Johannesburg.

Hobbs, R.J., 2000. Ecological repair following biotic invasions. In: Preston, G., Brown , G., Van Wyk , E. (Eds.), Best Management Practices for Preventing and Controlling Invasive Alien Species. Symposium Proceedings, pp. 181–188. ISBN0-620-26172-2.

Hobbs, R.J., 2007. Setting effective and realistic restoration goals: key directions for research. Restoration Ecology 15, 354–357.

Hobbs, R.J., Harris, J.A., 2001. Restoration ecology: repairing the earth's ecosystems in the new millennium. Restoration Ecology 9, 239–246.

Hughes, M.R., Colston, A., Mountford, J.O., 2005. Restoring riparian ecosystems: the challenge of accommodating variability and designing restoration trajectories. Ecology and Society 10, 12.

Holmes, P.M., 1989. Effects of different clearing treatments on the seed-bank dynamics of an invasive Australian shrub, *Acacia cyclops*, in the south-western Cape, South Africa. Forest Ecology and Management 28, 33–46.

Holmes, P.M., 2007. Targets for ecosystem repair in riparian ecosystems in Fynbos, Grassland and Savanna Biomes. Final Report to the Working for Water Programme. Department of Water Affairs and Forestry, pp. 42 (plus annexures).

Holmes, P.M., Cowling, R.M., 1997. The effects of invasion by *Acacia saligna* on the guild structure and regeneration capabilities of South African fynbos shrublands. Journal of Applied Ecology 34, 317–332.

Holmes, P.M., Richardson, D.M., Esler, K.J., Witkowski, E.T.F., Fourie, S., 2005. A decision-making framework for restoring riparian zones degraded by invasive alien plants in South Africa. South African Journal of Science 101, 553–564.

Jansson, R., Nilsson, C., Dynesius, M., Andersson, E., 2000. Effects of river regulation on river-margin vegetation: a comparison of eight boreal rivers. Ecological Applications 10, 203–224.

Jeffery, D.J., Holmes, P.M., Rebelo, A.G., 1988. Effects of dry heat on seed germination in selected indigenous and alien legume species in South Africa. South African Journal of Botany 54, 28–34.

King, J., Brown, C., 2006. Environmental flows: striking the balance between development and resource protection. Ecology and Society 11, 26.

Le Maitre, D.C., Van Wilgen, B.W., Gelderblom, C.M., Bailey, C., Chapman, R.A., Nel, J.A., 2002. Invasive alien trees and water resources in South Africa: case studies of the costs and benefits of management. Forest Ecology and Management 160, 143–159.

Marais, C., Wannenburgh, A.M., 2008. Restoration of water resources (natural capital) through the clearing of invasive alien plants from riparian areas in South Africa — costs and water benefits. South African Journal of Botany 74, 526–537 (this issue). doi:10.1016/j.sajb.2008.01.175.

Morris, T.L., Witkowski, E.T.F., Coetzee, J.A., 2008. Initial response of riparian plant community structure to clearing of invasive alien plants in Kruger National Park, South Africa. South African Journal of Botany 74, 485–494 (this issue). doi:10.1016/j.sajb.2008.01.177.

Nel, J.L., Roux, D.J., Kleynhans, C.J., Moolman, J., Reyers, B., Rouget, M., Cowling, R.M., 2007. Rivers in peril inside and outside protected areas: a systematic approach to conservation assessment of river ecosystems. Diversity and Distributions 13, 341–352.

Pretorious, M., Esler, K.J., Holmes, P.M., Prins, N., 2008. The effectiveness of active restoration following alien clearance in fynbos riparian zones and resilience of treatments to fire. South African Journal of Botany 74, 517–525 (this issue). doi:10.1016/j.sajb.2008.01.180.

PrinslooF.W., F.W., ScottD.F., D.F., 1999. Streamflow responses to the clearing of alien invasive trees from riparian zones at three sites in the Western Cape Province. South African Forestry Journal 185, 1–7.

Reinecke, M.K., Pigot, A., King, J.M, 2008. Spontaneous succession of riparian fynbos: is unassisted recovery a viable restoration strategy? South African Journal of Botany 74, 412–420 (this issue). doi:10.1016/j.sajb.2008.01.171.

RichardsonD.M., D.M., Van WilgenB.W., B.W., 2004. Invasive alien plants in South Africa: how well do we understand the ecological impacts? South African Journal of Science 100, 45–52.

Richardson, D.M., Holmes, P.M., Esler, K.J., Galatowitsch, S.M., Stromberg, J.C., Kirkman, S.P., Pyšek, P., Hobbs, R.J., 2007. Riparian zones — degradation, alien plant invasions and restoration prospects. Diversity and Distributions 13, 126–139.

Rountree, M.W., Rogers, K.H., 2004. Channel pattern changes in the mixed bedrock/alluvial Sabie River, South Africa: response to and recovery from large infrequent floods. In: De Jalon, D.G., Vizcaino, P. (Eds.), Proceedings of the Fifth International Symposium on Ecohydraulics, IAHR, Sapin, pp. 318–324.

Schmidt, E., Lotter, M., McCleland, W., 2002. Trees and Shrubs of Mpumalanga and Kruger National Park. Jacana, Johannesburg.

Sieben, E.J.J., Reinecke, K., 2008. Description of reference conditions for restoration projects in riparian vegetation from the species-rich Fynbos Biome. South African Journal of Botany 74, 401–411 (this issue). doi:10.1016/j.sajb.2008.01.176.

Shafroth, P.B., Beauchamp, V.B., Briggs, M.K., Lair, K., Scott, M.L., Sher, A.A., in press. Planning riparian restoration in the context of *Tamarix* control in western North America. Restoration Ecology 16.

SmithersJ.C., J.C., SchulzeR.E., R.E., PikeA., A., JewittG.P.W., G.P.W., 2001. A hydrological perspective of the February 2000 floods: a case study in the Sabie River Catchment. Water South Africa 27, 325–332.

Swift, C.C., Jacobs, S.M., Esler, K.J., 2008. Drought induced xylem embolism in four riparian trees from the Western Cape Province: insights and implications for planning and evaluation of restoration. South African Journal of Botany 74, 508–516 (this issue). doi:10.1016/j.sajb.2008.01.169.

Van DiggelenR., R., GrootjansA.P., A.P., HarrisJ.A., J.A., 2001. Ecological restoration: state of the art or state of the science? Restoration Ecology 9, 115–118.

Van Wilgen, B.W., Cowling, R.M., Le Maitre, D.C., 1998. Ecosystem services, efficiency, sustainability and equity: South Africa's Working for Water programme. Trends in Ecology and Evolution 13, 378.

Vosse, S., 2007. The restoration potential of fynbos riparian seed banks following alien clearing. Unpublished MSc Thesis, Stellenbosch University.

Vosse, S., Esler, K.J., Richardson, D.M., Holmes, P.M., 2008. Can riparian seed banks initiate restoration after alien plant invasion? Evidence from the Western Cape, South Africa. South African Journal of Botany 74, 432–444 (this issue). doi:10.1016/j.sajb.2008.01.170.

Whisenant, S.G., 1999. Repairing Damaged Wildlands. Cambridge University Press, Cambridge.

Witkowski, E.T.F., Garner, R.D., 2008. Seed production, seed bank dynamics, resprouting and long-term response to clearing of the alien invasive *Solanum mauritianum* in a temperate to subtropical riparian ecosystem. South African Journal of Botany 74, 476–484 (this issue). doi:10.1016/j.sajb.2008.01.173.

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